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MESH SURFACES FOR REFLECTOR APPLICATIONS

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OUTLINE

The topics listed in Figure 1 are those which I believe should be addressed in assessing the current state of metallic mesh technology for spaceborne reflector antennas. The work I shall discuss involves only the study of the properties of the conducting mesh material. To calculate the radiation patterns of antennas with conducting mesh reflectors, the electromagnetic properties of the mesh material must be integrated into an appropriate reflector antenna computer code. Such a code would take into account such factors as the curvature of the reflector surface, the radiation pattern(s) of the feed(s), etc. Many organizations have developed their own codes for these calculations. An excellent example of such a code is the one developed by Rahmat-Samii and Lee (ref. 1).

I. Why Mesh Reflectors?

II. Methods of Analysis

III. Measurements

IV. Problems of Current Interest

V. Future Research

Figure 1

MESH REFLECTORS BECAUSE

Listed in Figure 2 are three major reasons why metallic mesh materials are attractive for use as the reflector surface in large aperture reflector antennas in space.

1. Weight

2. Relative ease of deployment for required aperture size

3. Provides a reflector surface which can be adjusted in orbit

Figure 2

METHODS OF ANALYSIS

Figure 3 lists the methods which have been developed by various workers to calculate the electromagnetic properties - transmission and reflection coefficients as a function of angle and polarization - of infinite, periodic, rectangular wire grids.

The "average boundary condition" method (refs. 2 and 3) gives results which agree well with other methods as long as the grid opening is electrically small - less than 0.1 wavelength.

Rahmat-Samii and Lee (ref. 1) have studied the mesh material using two different methods of analysis. They used the average boundary condition method to model the mesh as a rectangular wire grid. They also modeled the mesh as "strip-apertures" - an infinite periodic array of apertures cut in a thin perfectly conducting plate. The analysis of the strip-apertures was carried out using a moment method technique similar to that reported by Chen (ref. 4). The wire-grid mesh formulation and the strip-aperture mesh formulation are not in agreement for all values of the mesh parameters. In particular, they found that the wire-grid mesh model did not obey reciprocity and, hence, the strip-aperture formulation was the more accurate of the two.

The Fourier series method of Hill and Wait (ref. 5) is very slowly converging for some values of mesh parameters.

The Spectral Domain Conjugate Gradient (SDCG) technique developed by Christodoulou and Kauffman (ref. 6) is an iterative technique for which convergence is guaranteed. The iterates are chosen so as to minimize the number of iterations required. This formulation can also accommodate grids with arbitrary surface impedance.

1. Average Boundary Conditions
   Kontorovich, 1963
   Astrakhan, 1968

2. Moment Methods - Strip Apertures
   Chen, 1970
   Rahmat-Samii & Lee, 1985

3. Fourier Series Expansion
   Hill & Wait, 1974

4. Spectral Domain Conjugate Gradient
   (SDCG)
   Christodoulou & Kauffman, 1986

All treat rectangular mesh openings

Figure 3

ACTUAL MESH SURFACE

Figure 4 is a line drawing of the actual woven mesh material magnified many times. Note the many small openings and loop contact points in addition to the large openings which correspond to the rectangular apertures in the mathematical models.

The meshes which have been fabricated have been woven using gold-plated molybdenum wire about 1 mil in diameter. The plating is typically around .25 μm thick. Meshes have been woven with anywhere from 10 to 32 openings per inch.

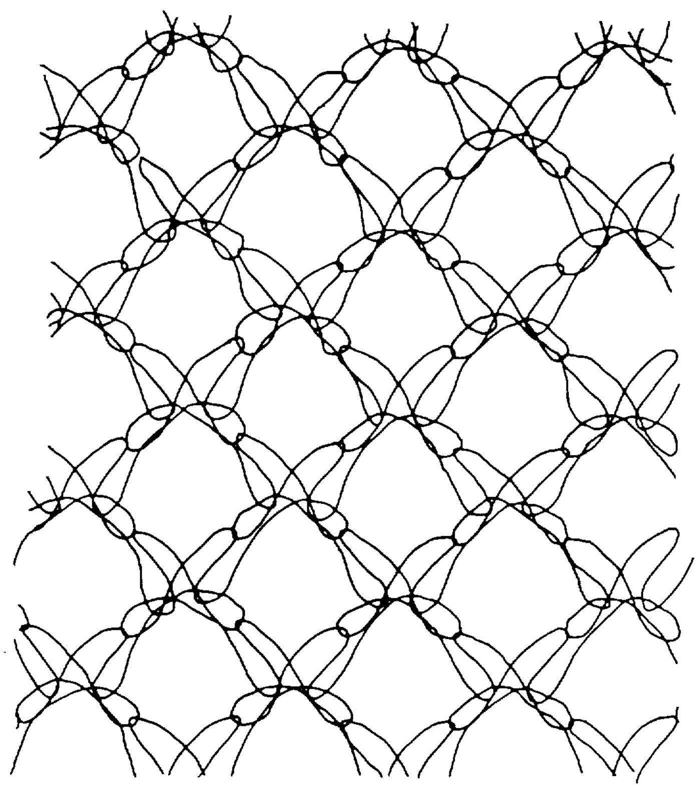
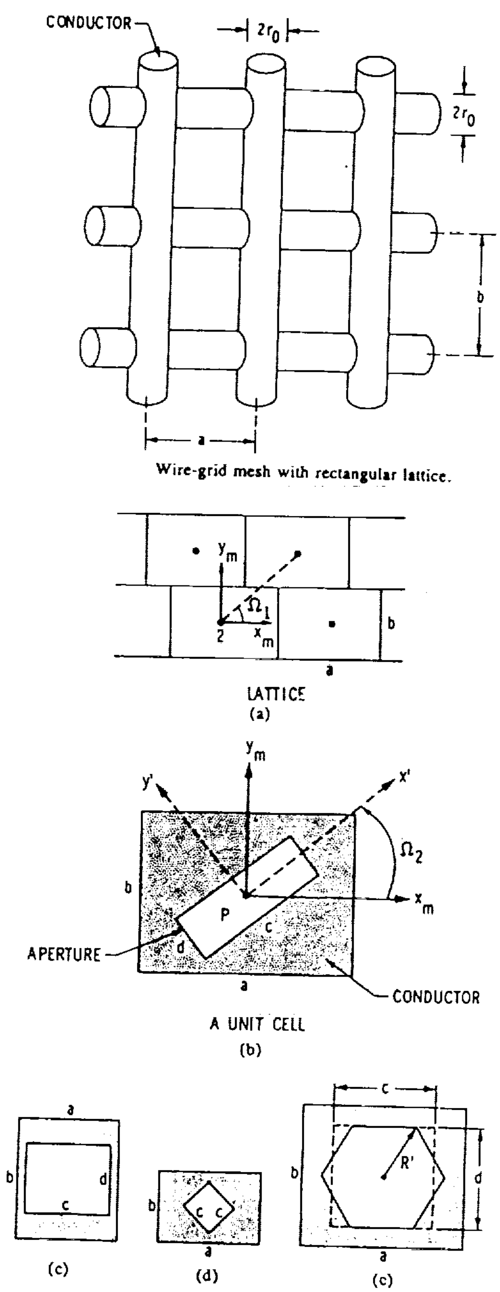


Figure 4

The sketches shown in Figure 5 define the geometries used in the mathematical analysis of the conducting mesh material.



Wire-grid mesh with rectangular lattice.

LATTICE
(a)

A UNIT CELL
(b)

(c) (d) (c)

Strip-aperture mesh model with different lattice configurations.

Figure 5

TRANSMISSION COEFFICIENTS USING WIRE-GRID AND STRIP-APERTURE MODELS

The mesh transmission coefficients versus angle of incidence, calculated using both the wire-grid and the strip-aperture formulations,are shown in Figure 6. Notice that $T_{\theta\phi} \neq T_{\phi\theta}$ for the wire-grid model indicating that the formulation does not obey reciprocity.

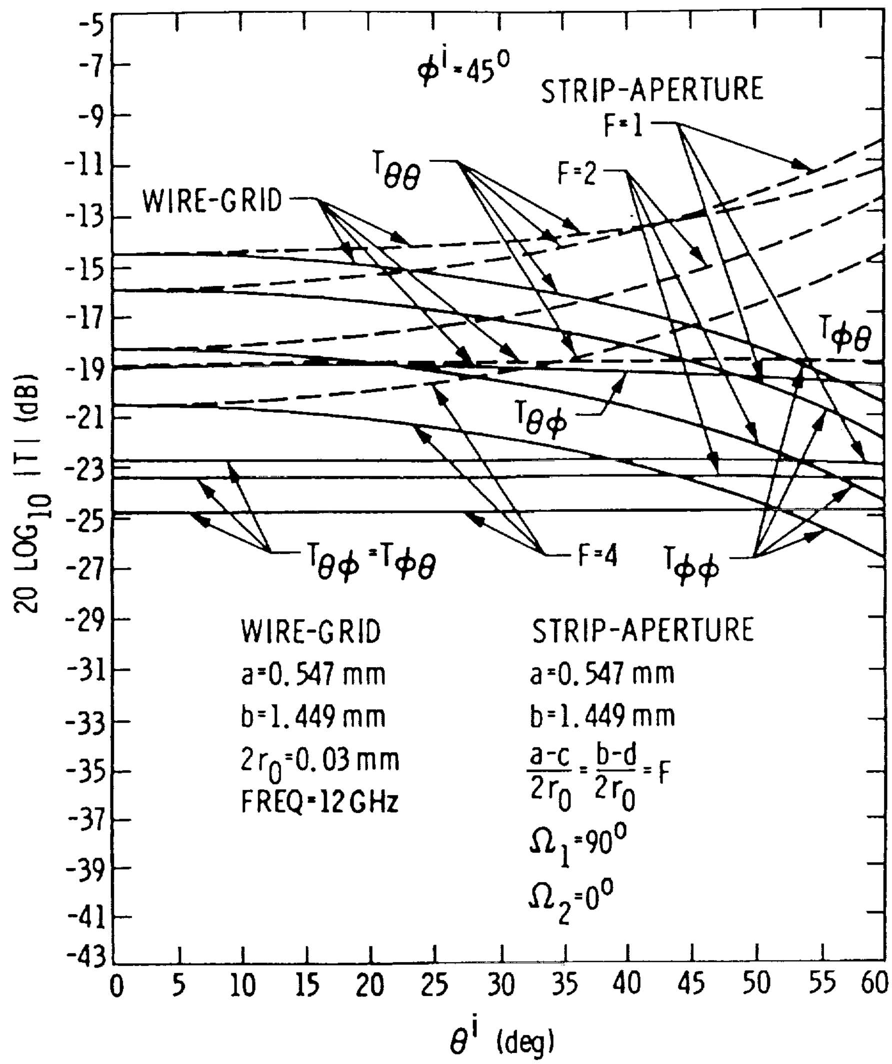
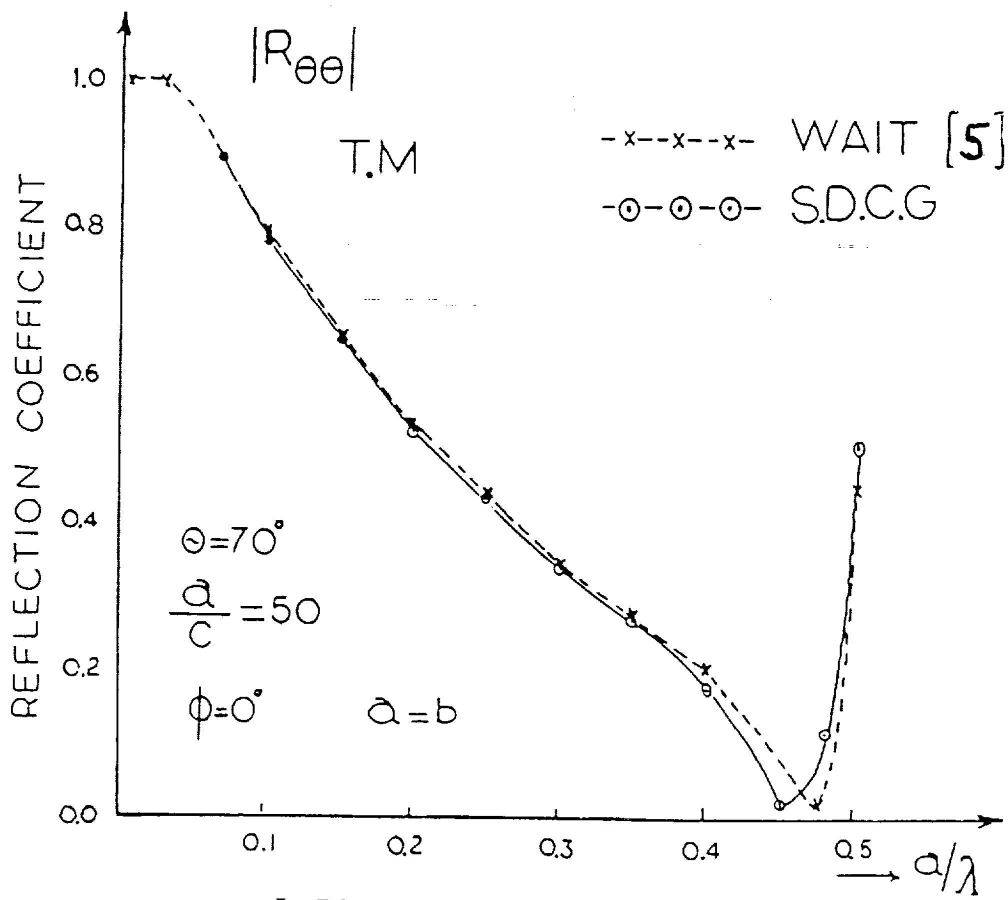


Figure 6

REFLECTION COEFFICIENT VS. MESH OPENING - TM POLARIZATION

Figure 7 shows a comparison of the reflection coefficient vs. mesh opening in wavelengths calculated by the method of Hill and Wait (ref. 5) and by the SDCG method of Christodoulou and Kauffman (ref. 6). As can be seen in the figure, the agreement between the two methods is quite good. This can be said of all of the analytical methods discussed earlier with the exception of the average boundary condition, which gives poor results for large mesh openings.

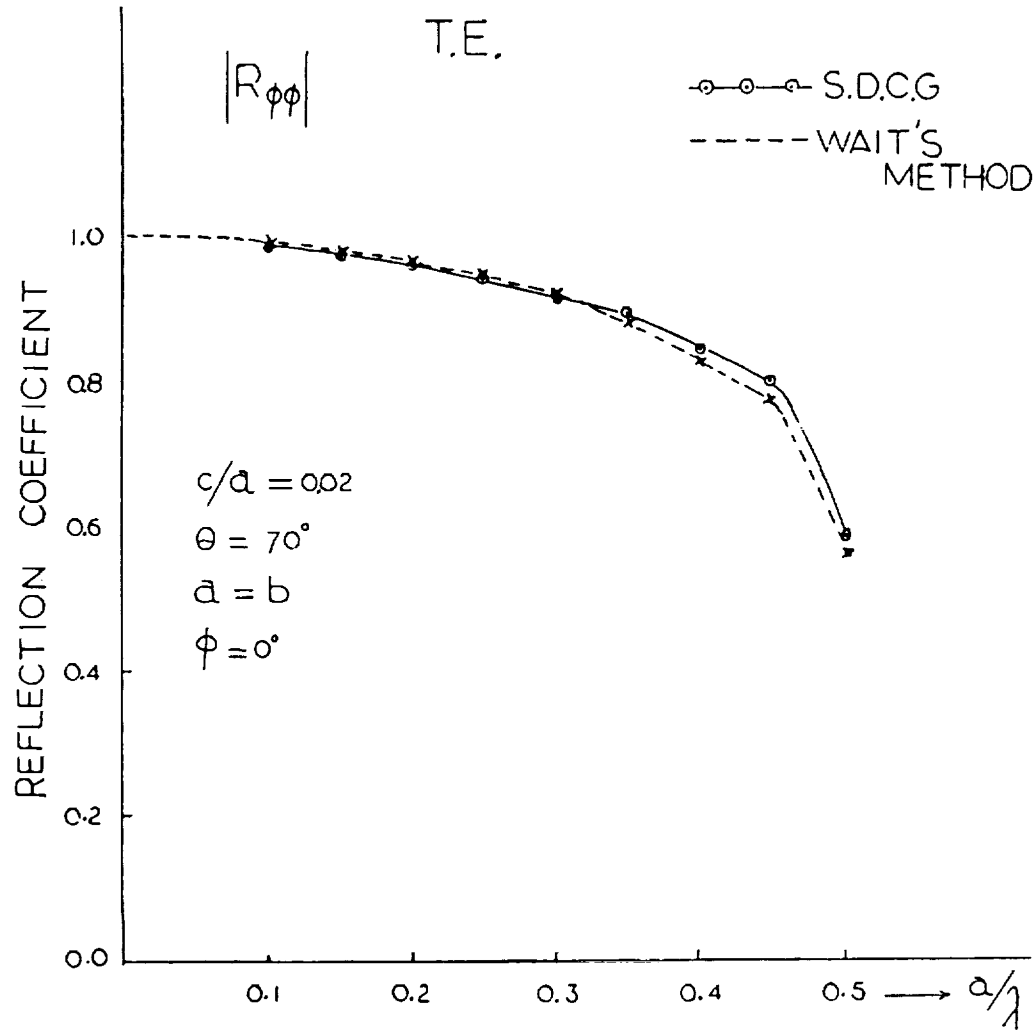


ϑ=70 deg., and φ=0 deg.

Figure 7

REFLECTION COEFFICIENT VS. MESH OPENING - TE POLARIZATION

Figure 8 shows the reflection coefficient vs. mesh opening for the orthogonal polarization. The same remarks made in discussing Figure 7 apply to Figure 8. Also, seeing comparisons with other calculations but not with measurements points toward one of the areas very much in need of further work: careful measurements of reflection and transmission coefficients as a function of angle of incidence, frequency, polarization and mesh opening. Our calculations agree well with one another but do they do a good job of modeling the actual mesh material?



ϑ=70 and φ=0 degrees

Figure 8

SKETCH OF THE 5.2 GHZ BUCKET RADIOMETER SET-UP

We leave now the discussion of the analytical methods which have been developed and turn our attention to the measurements which have been made.

Radiometer techniques offer a means of determining the ohmic losses of the mesh material. These measurements are power measurements: power reflected - reflectivity, power transmitted through the mesh - transmissivity, power absorbed - emissivity. The power emitted, or radiated, by the material is equal to the power absorbed if one neglects scattering. Measurements have shown this to be a good assumption. Conservation of energy requires that the sum of these three quantities, expressed as fractions of the incident power, be equal to one.

Knowledge of ohmic losses is very important if the material is to be used in a reflector antenna in a radiometer system. Such losses cause the brightness temperature measured by the system to be in error if they are not calibrated out or accounted for by some other means.

Figure 9 is a sketch of a system used by Harrington and Blume (ref. 7) to measure the emissivity, transmissivity and reflectivity of the gold-plated molybdenum mesh at 5.2 GHz. Four measurements with four different test configurations are required.

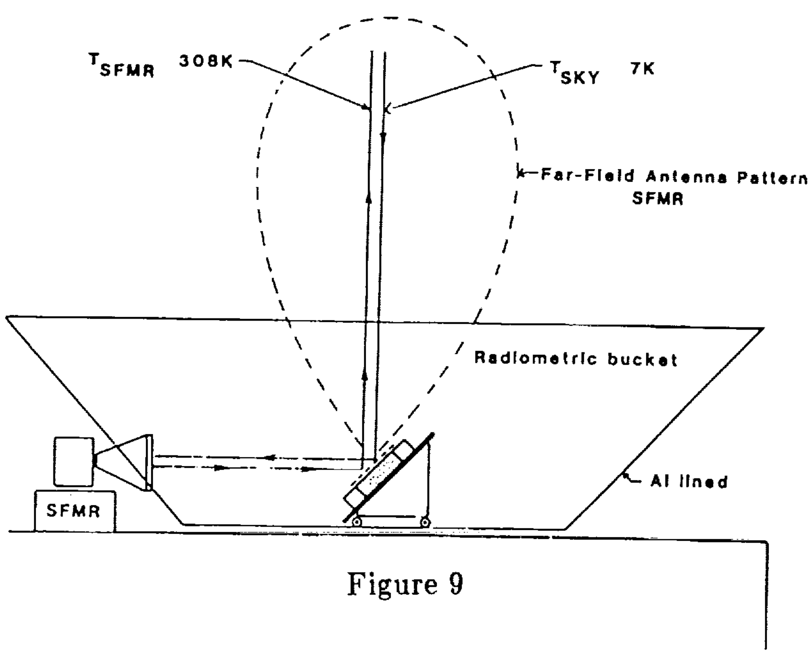


Figure 9

2.65 - GHZ CLOSED RADIOMETER

Figure 10 is a sketch of the radiometer used by Harrington and Blume (ref. 7) to measure the emissivity of the gold-plated molybdenum mesh at 2.65 GHz. Both of these systems and the measurements required are discussed in detail in the reference cited.

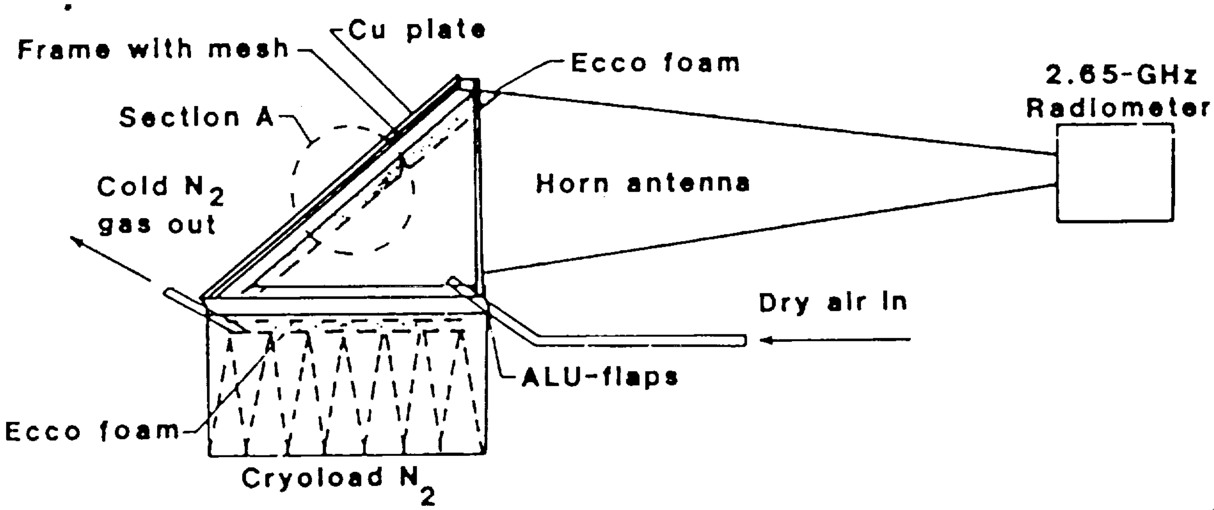


Figure 10

RADIOMETERIC TEST RESULTS

Figure 11 shows the test results at both 5.2 GHz and 2.65 GHz (ref 7).

TEST RESULTS-RADIOMETRIC BUCKET (5.2 GHz)

SAMPLE NO.	GD001	GD002
EMISSIVITY	.0048 ± .0002	.0050 ± .0003
	.0041 ± .0003	.0054 ± .0012
	.0049 ± .0003	.0050 ± .0003
	.0051 ± .0003	.0050 ± .0003
	.0046 ± .0004	.0059 ± .0004
MEAN:	.0047 ± .0004	.0053 ± .0004
REFLECTIVITY	.9724 ± .0005	.9743 ± .0005
	.9716 ± .0008	.9693 ± .0006
TRANSMISSIVITY	.0266 ± .0006	.0190 ± .0006
	.0213 ± .0008	.0233 ± .0003

(a)

TEST RESULTS-CLOSED SYSTEM (2.65 GHz)

SAMPLE NO.	GD001	GD002
EMISSIVITY	0.0185	0.0156
	0.0287	0.0167
	0.0134	0.0255
	0.0129	0.0183
	0.0137	0.0168
	0.0130	
MEAN:	0.0167 0.0062	0.0186 0.004

(b)

Figure 11

ADVANTAGES/DISADVANTAGES OF THE 5.2 GHZ AND 2.65 GHZ RADIOMETERIC MEASUREMENTS

Figure 12 lists the quantities measured and the problems encountered using the two systems.

A COOPERATIVE LaRC/NRL PROGRAM HAS DEVELOPED TWO DIFFERENT METHODS FOR MEASUREMENT OF THE ELECTROMAGNETIC PROPERTIES OF MESH MATERIAL.

(1) Radiometric bucket method

Measures reflectivity, emissivity and transmission
Problems: RFI, solar interference, weather, multiple measurements

(2) Closed system

Measures emissivity directly
Problems: Limited intergration time, heating/cooling rate limitations

Figure 12

PROBLEMS OF CURRENT INTEREST

Listed in Figure 13 are problems which have come to the attention of workers in this area which must be solved if mesh utilization for spaceborne antennas is to reach its full potential.

The first problem listed comes from observations on shuttle missions in which gold-plated materials, when exposed to the plasma discharge around the vehicle in low earth orbit, would oxidize in such a way as to form a Schottky barrier junction. These observations are discussed by Blume (ref. 8). If the contact points of the woven wire mesh form junctions of the type, its reflection and transmission properties and its ohmic losses would be altered dramatically. I will discuss this problem in more detail using the next two figures. However, before I do, let me mention briefly the second and third problems on the list.

The second problem comes from a desire for a mesh which performs well at higher frequencies - above 60 GHz. Such a mesh must be much smoother, with smaller cell size, than the current technology can provide. Some cooperative work between LaRC and a textile mill in North Carolina is being done to address this problem.

The third problem is listed simply to provide the information that Chase Hearn at LaRC has developed a resonant cavity technique for measuring the ohmic losses of these mesh materials.

1. Modeling Wire Mesh Contact Points

2. Woven Mesh Technology

3. Cavity-type Mesh Measurements (Power)

Figure 13

GOLD - MOLYBDENUM OXIDE - GOLD JUNCTION

Figure 14 provides a sketch of the Schottky barrier junction which may be formed by the oxidation of the material due to the action of the plasma discharge around the spacecraft in low earth orbit. Dr. Blume is currently planning an experiment to determine whether or not the gold/molybdenum mesh oxidizes as have similar materials during earlier space flights.

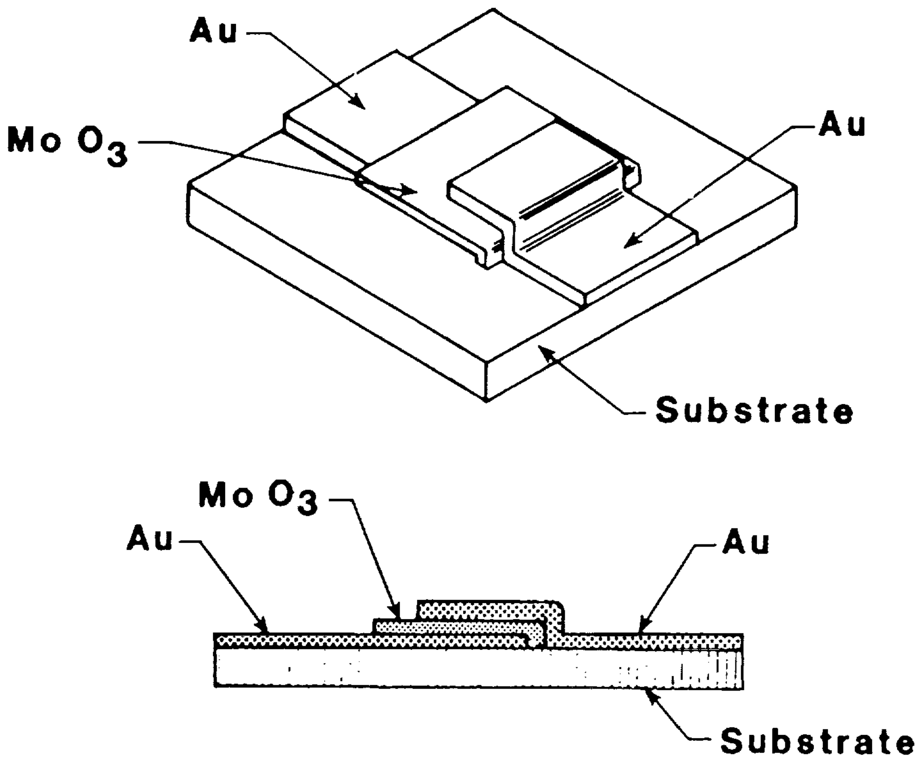


Figure 14

Figure 15 is a graph of capacitance of the diode versus temperature. Such variation is a cause for concern because spaceborne antennas are subjected to extreme temperature changes and thermal gradients. If the mesh contact points behave in this fashion, the reflection, transmission and loss properties of the mesh will undergo wide fluctuations with temperature.

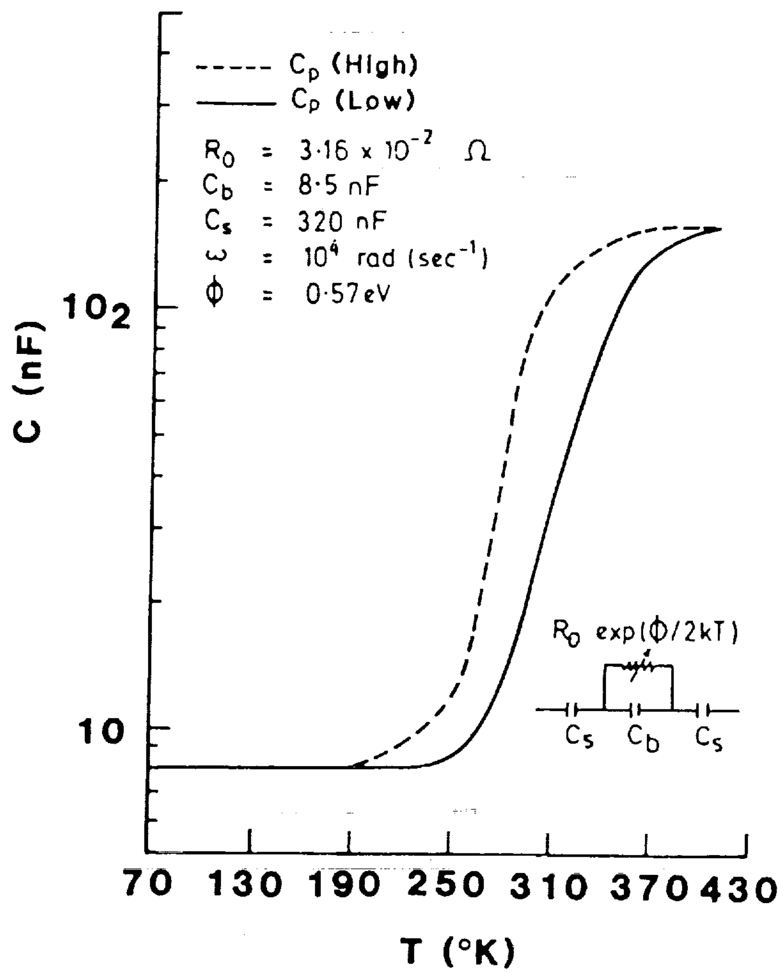


Figure 15

FUTURE RESEARCH

Figure 16 offers a list of those problems which, in my opinion, require further research.

A comprehensive set of measurements is needed not only to expand our knowledge of the mesh material but also to judge the adequacy of our analytical techniques.

The first gold - mobybdenum oxidation experiments are now being planned by Dr. Blume at LaRC with assistance from faculty and students at Old Dominion University.

Very limited tests are now under way on weaving tighter conducting mesh materials. Much more must be done if these materials are to be used at millimeter wavelengths.

1. **Measurement of Wave Properties - Reflection, Transmission, Polarization**
2. **Gold - Molybdenum Oxidation Experiments**
3. **Smoother, Tighter Woven Meshes for Higher Frequencies**

Figure 16